Genetically Modified Herbicide Resistant Rapeseed in Germany: A Socio-Economic Assessment

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Abstract

The cultivation of transgenic rapeseeds is currently banned in Germany. Considering the reversibility, irreversibility and uncertainty in the context of costs and benefits of introducing herbicide-resistance rapeseeds (HR), we determine the maximum incremental social tolerable irreversible costs (MISTICs) of this technology for Germany. Results indicate that banning HR genetically modified rapeseeds is only appropriate if German society values the possible total accumulated irreversible costs (from its introduction until infinity) of this technology as at least € 1.105 billion or € 13.8 per citizen.

Key Words

real option; rapeseeds; genetically modified organisms; irreversibility; social costs

1 Introduction

Many innovations in transgenic crops offer potential benefits to farmers but pose uncertain hazards to society. However, their adoption by farmers is only possible if the use of transgenic varieties is deregulated by society's institutions. This research aims to target the implicit regulatory challenge. Many studies have shown that compared with their conventional counterparts, different transgenic crops offer advantages related to cost saving or yield increases (FINGER et al., 2011; KLÜMPER and QAIM, 2014; ZILBERMAN et al., 2010). On the other side, society's health-related and environmental concerns make transgenic crops a controversial topic, and some states reject this technology because of its potential long-term irreversible costs. Decision makers have to weigh these costs against the potential benefits to choose between the options of immediate releases or postponed decisions.

Rapeseed is used as animal feed, for human consumption, in industrial production, and – increasingly – as biofuel. Approximately 72.5 million tonnes of rapeseeds are grown annually (FAO, 2015); main producers are Europe, North America, China, India and Australia. Europe is the world's principal rapeseed-producing region, with production amounting to 25.6 million tonnes in 2013. Within Europe, Germany and France are the main rapeseed cultivators, accounting for approximately 40% of the total European production (FAO, 2015). However, genetically modified (GM) herbicide-resistance (HR) rapeseed varieties are cultivated only in Canada, the U.S., Australia and Chile. Currently, approximately 25% of the global annual rapeseed production (on approximately 36 million hectares) is genetically modified; moreover, such production displays an upward trend (JAMES, 2014). In 2012, 98% of the Canadian rapeseed production area (8.37 million hectares) was used for cultivating GM HR varieties (BROOKES and BARFOOT, 2014). Farmers in the European Union (EU) cannot experience possible benefits from cultivating GM HR rapeseeds, as currently none such variety is approved for cultivation. Nevertheless, six GM HR rapeseeds varieties a currently approved for food and feed and import and processing (GMO-COMPASS.ORG, 2015). The main reason for a ban of GM crops cultivation is that European decision makers evaluate possible irreversible costs of the technology as too significant compared with its potential benefits (ZILBERMAN et al., 2015). However, to our knowledge, so far no scientific study exists that credibly values either the possible irreversible costs or the possible benefits of HR rapeseeds for EU member states, their farmers and their citizens. To fill this gap with respect to scientific evidence, we conduct a socio-economic ex ante assessment of GM HR rapeseeds in Germany in this study. The focus on only one European country is justified by the opt-out clause, which gives single member countries the option to decide whether or not to allow GM cultivation on their territory even though a GM variety is approved for cultivation on European level.

The introduction of Clearfield rapeseed variety in the German market in 2012 – a conventional rapeseed variety with very similar agronomic characteristics as GM HR rapeseeds – highlighted that the irreversible hazards linked to agronomic disadvantages do not hinder the GM HR rapeseeds' approval process. This example demonstrates that the EU's opposition to approve GM crops is based on breeding technic characteristics and other political economy factors – to a lesser extent – the specific agronomic principle of operation.

We analyse the socio-economic potential of an intermediate release of GM HR rapeseeds by considering private and social reversible and irreversible costs and benefits to determine the maximum incremental social tolerable irreversible costs (MISTICs) (DEMONT et al., 2004; WESSELER et al., 2007). MISTICs are based on the real options approach and can identify an upper bound – up to which the release or investment in a new technology can still be considered economically justified – for irreversible social costs. When a new technology is developed and submitted for cultivation approval, decision makers face the choice or option to authorising or banning its market introduction. A temporary ban is equal to postponing the decision and waiting for further information. The possibility of introduction implicates an option value, which is determined in this study as well. The decision criteria includes irreversibility and uncertainty of expected benefits and costs to society. The option should only be exercised if the benefits of an immediate release outweigh those of keeping the option and postponing the decision. MISTICs can be used to conduct a monetary evaluation of the situation as well as structure the decision finding process. The potential benefits of GM technology contrasted with society's health-related and environmental concerns and make transgenic crops based on GM a controversial topic. For modelling purposes, we formulate assumptions based on scientific studies examining the agronomic effects of GM HR rapeseeds and combine these findings with the rapeseed cultivation situation in Germany to calculate the possible benefits and costs for society. Furthermore, we aim to place an economic value on potential savings in carbon dioxide (CO_2) emissions to value the related positive environmental impacts.

Previous studies that socio-economically assess GM technology can be distinguished into those that take an ex post or an ex ante perspective. BROOKES and BARFOOT (2014) determined ex post that since their introduction in 1999, GM HR rapeseeds had provided benefits worth US$ 268.8 million for U.S. agriculture[1]. FAGERSTRÖM et al. (2012) refer to a former study by FAGERSTÖRM and WIBE which analyzed a possible economic gain of ca. € 10 million or ca. € 116 per hectare for Swedish farmers when farming HR rapeseeds. ZILBERMAN et al. (2010), FINGER et al. (2011) and KLÜMPER and QAIM (2014) provided analytical overviews of ex post studies analysing the economic effect of GM crops such HR soybeans, maize and cotton and HR soybeans for different regions. RAMASAMY et al. (2007) and STEIN et al. (2006) conducted economic ex ante assessments of different GM crop innovations. Ex ante studies using the theoretical concept of MISTICs have been conducted for HR sugar beets (DEMONT et al., 2004) and Bt and HR maize (WESSELER et al., 2007). In this study we determine MISTICS for GM HR rapeseeds in Germany and show how real option calculation can be used to economically evaluate the option of this innovation.

The paper proceeds as follows. The next section develops the theoretical concept of MISTICs based on a cost-benefits assessment structure. The following sections provide information on empirical data and followed by the presentation of the results as well as their discussion. The final section summarises our findings and offers conclusions.

2 Theoretical Model and Methods

In the approval process for innovations, decision-making bodies such as the European Commission should aim to maximise society's welfare (V), which can be described as

$$maxV = (0, W + J - I) \tag{1}$$

where W is the discounted total future incremental[2] net benefits and J and I are the discounted total future irreversible benefits and costs associated with the deregulation of the technology, respectively.

Net present value (NPV), as the standard neoclassical decision-making criterion, suggests to deregulate an innovative technology if the expected social reversible net benefits exceed the social reversible net costs. However, this approach considers neither uncertainty and irreversibility nor the possibility of postponing the decision. In our analysis, we use an ex ante assessment model based on real options theory that explicitly considers these aspects. The theoretical basis for our analysis utilises the real options approach developed by DIXIT and PINDYCK (1994) and

[1] The annual rapeseed cultivation area in U.S. is 30-50% compared to Germany.

[2] As 'incremental', we consider the difference between the benefits or costs of GM crops and the benefits or costs of their non-GM counterparts.

McDonald and Siegel (1986). In finance, this approach is considered an investment-decision-making tool, given its ability to incorporate the uncertainty of future revenues, irreversibility of investments and possibility of postponing investment decisions. Our socio-economic assessment model can be regarded as an information or decision-making tool for politicians or decision-making bodies. The model's outputs are an option value, which gives a value to the possibility of introduction and a MISTIC value, which can be used as a decision criterion.

We apply our model to the situation in which a seed company applies for deregulation of GM HR rapeseeds in the EU. Similar to financial investment options, decision-making bodies can approve such an application immediately or postpone the decision and wait for further information. The real options approach for MISTICs is based on an American call option, which gives the holder the right – but not the obligation – to exercise the option at any point during the validity period. We interpret the concept such that the decision maker has the right, but not the obligation, to authorise a new technology at any point during an infinite validity period.

Through our analysis, we demonstrate that a decision-making body aiming to maximise social welfare should release GM HR rapeseed lines immediately in a case in which MISTIC values are smaller than the actual irreversible social costs (I).

2.1 Reversible and Irreversible Incremental Private and Social Benefits and Costs

It is important to distinguish between reversible and irreversible incremental benefits and costs, particularly in terms of private (farmer), non-private (non-farmer citizens) and social (the sum of private and non-private) welfare effects. Reversible benefits and costs are only present for the period during which the farmer cultivates GM rapeseeds. Reversible benefits are defined as benefits of low tillage cultivation systems that are applicable due to the plants' HR characteristic (i.e. yield increase, reduction in cultivation costs due to fewer machinery hours and cheaper herbicide treatment). Conversely, irreversible benefits and costs are those that persist even if GM rapeseeds are no longer cultivated. We consider reduced CO_2 emissions due to lower fuel usage as irreversible benefits (Demont et al., 2004; Scatasta et al., 2007). Irreversible costs might relate to possible negative effects on biodiversity, transfer of genes from GM rapeseeds to bacteria, outcrossing in wild or conventional relatives, human health hazards, biosafety regulation costs as well as development of weed resistance (Green, 2007; Powles and Yu, 2010). Irreversibility implies that once an action is taken, it is impossible to revert to the initial situation that prevailed before the action was taken. The possibility of irreversible costs for society following the introduction of genetically modified organisms (GMOs) in agriculture is regarded as a major reason for the reluctance in European society and politics to allow GMOs. Table 1 summarises the reversible and irreversible incremental private and social benefits and costs for GM HR rapeseed production considered in this study. Furthermore, we include the symbols used throughout the text.

The real options approach is particularly relevant if the action (i.e. development, release, or adoption) is accompanied by irreversible costs. This is plausible to the extent that if all costs accompanying an investment decision are reversible, there would be no incentives to postpone the investment (provided that the immediate benefits exceed the costs) even if future benefits and costs are uncertain. However, irreversibility reduces the benefits. Consequently, the presence of irreversibility gives value to the possibility of postponing the decision and wait for further information regarding the hazards posed by the particular innovation.

Table 1. Reversible and irreversible incremental private and social benefits and costs

		Private (farmer) aspects	Non-private (non-farmer) aspects	Social aspects	Symbol
Benefits/ hectare	incremental, irreversible	n/a	reduction in CO_2 emission	∑(private aspects + non-private aspects)	***J***
	incremental, reversible	higher yield (10%), reduction in cultivation costs (low tillage)	n/a		***W*** (net benefits)
Costs/ hectare	incremental, reversible	n/a	n/a		
	incremental irreversible	n/a	possible negative effects for society (e.g. increasing health cost, loss in biodiversity)		***I***

Source: authors' compilation

2.2 Maximum Incremental Social Tolerable Irreversible Costs (MISTICs)

The real options approach developed by DIXIT and PINDYCK (1994) considers the optimal time to invest (irreversible) sunk costs (S) in return for uncertain infinite reversible benefits of a project (W), given that W evolves according to a geometric Brownian motion (GBM), which can be written as

$$dW = \alpha W dt + \sigma W dz \quad (2)$$

in which

$$dz = \varepsilon_t \sqrt{dt}, \varepsilon_t \approx N(0,1) \quad (3)$$

where α is the drift rate, dt is the change over time, σ is the variance parameter and dz is the increment of a Wiener process, which is independently and identically distributed according to a normal distribution with a mean of zero and a standard deviation of one. Equation (2) implies that the project's current value is known, but future values are log-normally distributed with a variance that grows linear over time (SCHWARTZ and TRIGEORGIS, 2004).

Based on continuous claim analysis and dynamic programming, DIXIT and PINDYCK (1994) showed that it is optimal to invest if W exceeds not only the sunk costs S but the critical value W^*:

$$W^* = \frac{\beta}{(\beta-1)} S \quad (4)$$

The latter can be derived by including uncertainty and irreversibility through the hurdle rate ($\frac{\beta}{(\beta-1)}$), which will be subsequently explained in more detail. As $\beta > 1$, the hurdle rate increases the critical value for the investment decision (W^*) compared with a classical investment decision criterion ($W_C^* = S$). To introduce MISTICs, we consider $S = I - J$. An option to introduce GM rapeseeds should be exercised if W is at least W^*. If W is less than W^*, the decision should be postponed.

In the context of GM crops, European society is concerned about potential but uncertain irreversible costs. However, based on the current state of knowledge, quantifying the social irreversible costs (I) caused by introducing GM HR rapeseeds appears unfeasible. But we can resolve equation (4) to focus on the critical value for I (I^*).

$$I^* = \frac{\beta-1}{\beta} W + J \quad (5)$$

The new interpretation of the equation is that an option to introduce the GM HR rapeseed should be exercised if I is smaller than I^*. If I is greater than I^* the decision should be postponed. I^* is the real option decision criteria defined as MISTICs (WESSELER et al., 2007). With MISTICs we determine the upper limit of the sum of the irreversible social costs (J) and reversible net benefits (W) weighted by the hurdle rate until it would be socially optimal to immediately release an innovation e.g. HR GM rapeseed). Or if a technology is not released (as HR GM rapeseed) the MISTICs value can be seen as benefits the society is willing to sacrifice for the sake of not introducing GM rapeseed production.

2.2.1 Hurdle Rate

The hurdle rate increases in accordance with the increasing volatility of previous gross margins, as we assume that past volatility makes future returns more risky and uncertain. We calculate the hurdle rate $\left(\frac{\beta}{1-\beta}\right)$ using gross margins per hectare for German conventional rapeseed production in Germany for 2007–2013:

$$\beta = \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{r-\delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1 \quad (6)$$

$$\delta = \mu - \alpha \quad (7)$$

where r is the risk free rate of return, δ is the convenience yield and σ is the volatility of W. The convenience yield (δ) is the difference between the risk-adjusted rate of return (μ) and the mean annual rate of return (α) (DIXIT and PINDYCK, 1994) and can be expressed as

The risk-adjusted rate of return (μ) is calculated using the capital asset pricing model (CAPM) (HULL, 1999). The mean annual rate of return α can be determined as follows MUßHOFF and HIRSCHAUER (2003):

$$\hat{\alpha} = \left(\frac{\sum_{t=1}^{T} ln\left(\frac{w_{ha_t}}{w_{ha_{t-1}}}\right)}{n-1} \right) \quad (8)$$

where w_{ha} represents the net incremental benefits per hectare per year that could have been achieved with GM rapeseeds in Germany at time t. For t, we consider the period 2007-2013.

2.2.2 Social Incremental Reversible Net Benefits (W_T) and Social Incremental Irreversible Benefits (J_T)

W_T and J_T are calculated as the discounted sum of annual incremental reversible net benefits (w) and annual incremental irreversible benefits (w), respectively, from the time released (T) until infinity. The release of an innovation follows an adoption process that needs to be considered for our calculation of discount.

2.2.3 Adoption

For agricultural crop innovations, the adoption process leads to an increase in the area allocated to the new variety over time. We assume that the adoption process follows an S-shaped curve (GRILICHES, 1957; ROGERS, 2003), which can be formulated as

$$\theta(t) = \frac{\theta_{max}}{(1+e^{-(a+bt)})} \tag{9}$$

The parameters a and b can be estimated using non-linear optimisation,3 where a is a constant, b is the rate of adoption and θ_{max} is the maximum level of adoption. We assume that θ_{max} refers to the last year of observation with respect to the adoption data used.

2.2.4 Social Reversible Net Benefits (W_T)

W_T is the social incremental reversible net benefit, which equals social incremental reversible benefits minus social incremental reversible costs. The total annual value of W_T $[w(t)]$ under consideration of an adoption process is calculated as

$$w(t) = w_{max}\theta(t) \tag{10}$$

with the maximum aggregated benefit under complete adoption (w_{max}) expressed as

$$w_{max} = w_{ha} * h \tag{11}$$

where w_{ha} is the incremental reversible net benefits per hectare and h is the total area in Germany (in hectares) used for rapeseed cultivation.

$$W_T = \int_T^{\infty} w_{max}\theta(t)e^{-\mu t}dt \tag{12}$$

The expected discounted present value of $w(t)$ from T until infinity (W_T) is calculated as

2.2.5 Social Incremental Irreversible Benefits (J_T)

Similar to the process used to derive W, we determine J as

$$J_T = \int_0^{\infty} j_{max}(t)\theta(t)e^{-\mu t}dt \tag{13}$$

$$j_{ha} = \chi g_{nt} \tag{14}$$

where χ represents external costs per tonne of CO_2 emissions and g_{nt} is the amount of reduced CO_2 equivalent due to low tillage cultivation.

[3] Alternatively, we estimated a und b using linear regression and obtained similar results.

2.2.6 Option Value

The possibility of waiting for further information and thus delaying the exercise of an option is an essential criterion within the financial interpretation of a real option. Transferring this to our analytical problem, the option to act or deregulate has a value itself as it allows the owner a possibility to reduce losses by postponing the action.

The value of an option to invest with uncertain revenues but known costs has the form

$$F(W) = AW^{\beta} \tag{15}$$

where A is a constant that can be determined as follows (DIXIT and PINDYCK, 1994):

$$A = (W^* - I)/(W^*)^{\beta} \tag{16}$$

For MISTICs where we determine I^* instead of W^*, we can reformulate Equation (16) as

$$A = (W - I^*)/(W)^{\beta} \tag{17}$$

Figure 1 shows the relationship between the optimal value to invest (W^*) and the MISTICs value (I^*) determined by the real options approach as well as the relationship between I^{NPV} (investment costs considered in positive terms) and W^{NPV} determined with NPV calculation.

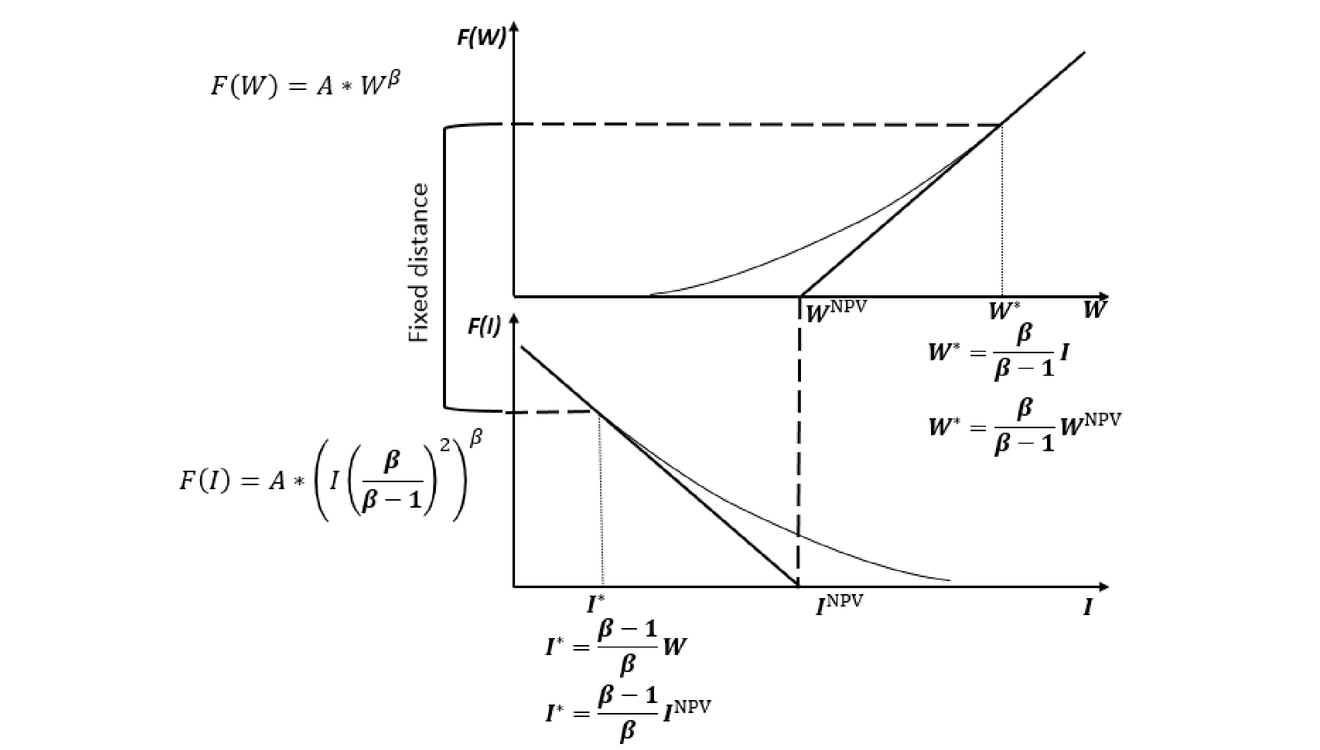
According to the NPV investment decision, it is optimal to invest if $I^{\mathrm{NPV}} \leq W^{\mathrm{NPV}}$. $I^{\mathrm{NPV}} = W^{\mathrm{NPV}}$, as depicted in Figure 1, denotes the investment threshold. Based on this threshold value, W^* and I^* can be determined by the factors $\frac{\beta}{\beta-1}$ and $\frac{\beta-1}{\beta}$, respectively. The option value for W^* ($F(W^*)$) and I^* ($F(I^*)$) are equal.

3 Data

For the ex ante assessment of future revenues, we assume that the benefits derived from GM HR rapeseed cultivation in Germany will equal the related benefits observed in countries where GM HR rapeseed cultivation has already been deregulated.

We completed a time series for the incremental, achievable gross margins per hectare with respect to rapeseed cultivation in Germany for the period 2007-2013 for a situation in which GM HR rapeseed cultivation had been adopted. We compare conventional rapeseed cultivation incorporating ploughing to that using a low tillage cultivation system, as the latter would be possible with GM HR rapeseed seeds. Table 2 list the single considered cultivation steps in each system.

Figure 1. Relation between the option values F(I) and F(W)



Source: authors' own graph

Table 2. Cultivation steps for conventional and GM HR rapeseeds production

Conventional	GM HR (Low tillage)
Soil sample (every 5th year)	Soil sample (every 5th year)
Fertilization	Fertilization
Ploughing	
Harrowing	
Seeding	Seeding
Herbicide application (500 g Metazachlor, 500 g Dimethenamid and 85 g Clomazone)	Herbicide application (1088 g Glyphosate)
Spray application (fungicide)	Spray application
Growth control	Growth control
Fertilization	Fertilization
Growth control	Growth control
Fertilization	Fertilization
Spray application (fungicide, insecticide)	Spray application
Harvest	Harvest
Transport	Transport
Chalk	Chalk
Tillage	
Tillage	

Source: authors' compilation

The total costs for rapeseed cultivation depend on the prices of fertilizer, herbicides, fungicides, insecticides, seed, machinery, fuel, insurance and seed drying. Information on prices was supplied by the State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt[4] (LLFG, 2014). Only the direct cost for herbicide application (herbicide and associated application costs) differs between conventional and low tillage cultivation systems. We adjusted herbicide costs by annual prices for glyphosate (BAYWA, 2014). Variable machinery costs are taken from Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL). In addition, based on BROOKES and BARFOOT (2014), we assumed an annual yield surplus of 10% as incremental reversible benefits. However, we will also present results of our model without a 10% yield increase since it remains uncertain if there will be yield differences between a GM HR and an intensive conventional rapeseed production.

The average conventional rapeseed yield (DESTATIS, 2014b) as well as the cultivation area (DESTATIS, 2014a) in Germany is obtained from the DESTATIS online database. Rapeseeds' prices are based on nearby futures prices from the MATIF (AHDB, 2014). We ignore potential shifts in demand or price changes due to GM rapeseed production. All

[4] Saxony-Anhalt is a typical production area for rapeseeds in Germany.

monetary data are deflated using 2013 as the base year and annual inflation rates from DESTATIS (2014c).

Concerning the environmental impact from the introduction of GM HR technology, we consider reduced CO_2 emissions due to less cultivation steps (Table 2). The differences in CO_2 emissions between conventional and low tillage cultivation are, on average, 160.89 kg CO_2 equivalent/ha/a. The value was derived using the KTBL dataset and the ENZO2 Greenhouse Gas Calculator (IFEU, 2015). We evaluated the CO_2 equivalent using € 65.18/tonne of carbon (C)[5] following the conclusions in TOL (2011) on the social evaluation of carbon. With the factor 0.2727 to convert tonnes of CO_2 into tonnes of C (EPA, 2004) we approximate environmental benefits from reduced CO_2 emission with € 2.86/ha on average. Table 3 summarises the different cultivations systems in terms of revenues, cost, incremental reversible private benefits and incremental irreversible non-private benefits over the years 2007-2013.

The incremental private benefits are quiet high compared to empirical based incremental benefits in other studies. BROOKES and BARFOOT (2014) calculated average annual incremental benefits from GM HR rapeseeds for Canadian (and similar for American) farmers of $/ha: 52. QAIM (2009) even reports that net benefits from HR rapeseeds have been small or partly negative to Canadian and American farmers since the seed premium payed to the seed company was similar to the benefits. For our ex ante approach we calculated potential benefits and ignored seed premiums, which can be very different according to trait or region. Furthermore, a 10% increase yield increase – as observed by BROOKES and BARFOOT (2014) – has an high impact in absolute terms, considering that the average rapeseed yields for Germany are around twice as high compared to U.S. and Canada (FAO, 2015). Eventually, since our gross margins are constructed and not empirical reported they might overestimate potential savings. However, our estimated increase in gross margin of ca. 25% is below the increase 40% assumed by (BREUSTEDT et al., 2008).

To estimate the speed and magnitude of future adoption of GM technology, we use the adoption information for hybrid rapeseeds in Germany. The data shows the annual line and hybrid rapeseed cultivation area for the period 1996-2014 (KLEFFMANN-GROUP, 2012). Even though hybrid and GM rapeseed innovations differ in breeding technology, using these data enables us to estimate an adoption function for a recent yield-increasing innovation[6] for the German rapeseed market. However, for the adoption of GM HR rapeseeds further market and farming aspects such as consumer preferences for conventional compared with GM rapeseeds, segregation cost or price differences between conventional and GM rapeseeds, expected liability from cross pollination, producers' neighbours attitude towards GM technology, technology fees and farm characteristics will be important (BREUSTEDT et al., 2008).

Table 3. Cultivation costs and benefits

Year	Rapeseed production revenue (€/ha)		Rapeseed production costs (€/ha)				
	GM HR	Conventional	GM HR	Conventional	Incremental reversible private (farmer) benefits (€/ha)		Incremental irreversible non-private (non-farmer) benefits (€/ha)
					With yield increase	W/o yield increase	
2007	1010.65	918.77	457.32	574.27	208.83	116.95	5.81
2008	1667.26	1515.69	544.47	639.01	246.11	94.54	5.81
2009	1516.28	1378.44	647.34	738.89	229.39	91.55	5.79
2010	1231.04	1119.12	629.05	705.18	188.04	76.13	5.82
2011	1389.09	1262.81	565.29	645.31	206.3	80.02	5.79
2012	1831.58	1665.08	593.22	682.65	255.94	89.43	5.77
2013	2052.97	1866.34	612.19	709.34	283.78	97.15	5.76

Source: authors' calculation, see text

5 The original value is $80/tonne of C and the considered exchange rate US$1 = 0.8148.

6 Hybrid rapeseeds were introduced to the German market in 1996.

Table 4. Monetary effect GM HR rapeseed cultivation in Germany

	Society	Per citizen	Per household	Per hectare rapeseed
MISTICs for 2014 (for an infinite time horizon) in € with yield increase	1 115 173 589	13.8	27.64	976.99
MISTICs for 2014 (for an infinite time horizon) in € w/o yield increase	588 052 775	7.28	14.58	396.1
Possible forgone social benefits in 2013 in € with yield increase	416 026.68	0.005	0.01	286.58
Possible forgone social benefits in 2013 in € w/o yield increase	142 421.9	0.002	0.004	99.94

Note: maximum incremental social tolerable irreversible cost (MISTICs) are calculated for German society comprising a population of 80.82 million citizen (DESTATIS, 2014d), 40.34 million households (EUROSTAT, 2014) and a total rapeseed cultivation area of 1.47 million hectares. To calculate a value per hectare rapeseeds we assume that rapeseed cultivation on the same field is only possible every third year.
Source: authors' calculation, see text

For the ex ante perspective of our study, we assume the absolute area (in hectares) used for rapeseed cultivation will remain constant at the average level for the period 2010-2013. We assume that only the relative amount of GM rapeseed and conventional rapeseed will change over the course of the adaptation process.

The risk-free rate of return of 3.37% is the average interest rate from 2007-2013 for German 30-year federal bonds (DEUTSCHE BUNDESBANK, 2014). As a broad index, we used the average revenue per hectare for special crop farms in Germany published by the German Federal Ministry of Food and Agriculture covering 2003-2013 (BMELV, 2015). Therefore, we assume this revenue level as the revenue to be achieved by an average crop farmer as the risk is decreased by a more diverse crop production portfolio. In comparison, in a finance-based analysis, broad index stocks such as S&P 500 or DAX are used.

4 Results and Discussion

Our results suggest that during 2007-2013, the average net incremental reversible private benefits of GM HR rapeseeds compared with their conventional counterpart would have been € 242.58/hectare/year.
The adoption function was determined as

$$\theta(t) = \frac{0.84}{\left(1+e^{-(-2.88+0.29t)}\right)} \quad (18)$$

To apply the real options concept, we estimated a risk-adjusted rate of return (μ) of 8.19%, a drift rate in net incremental benefits (α) of 4.08% and a hurdle rate of 1.58. Assuming a yield increase of 10% we estimated W_{2014} and R_{2014} as € 1.73 billion and € 39.308 million, respectively. We determined MISTICs as € 1.115 billion for German society in 2014 [based on Equation (5)]. Thus, immediate introduction of GM HR rapeseeds in Germany in 2014 would have been economically justified if the actual social irreversible costs did not exceed this value. MISTICs are found to be € 976.99 per hectare[7] cultivated with rapeseed and € 13.80 per citizen. The mentioned results and the model results without a 10% yield increase are summarized in Table 4. Without yield increase-a realistic scenario due to an already intensive conventional rapeseed production with high yield in Germany – MISTICs and possible forgone benefits are about half.

The option value [$F(W)$] of € 249.058 million [based on Equation (15)] can be interpreted as the monetary value of German society introducing GM HR rapeseed cultivation at some point, i.e. it can be regarded as the societal value of the possibility of access to this technology. Accordingly, the government could use this value as a benchmark for making allocation decision with respect to research funds.

Previous studies derived MISTICs values in a manner similar to our estimates. For the introduction of GM HR sugar beets in Europe, DEMONT et al. (2004) determined MISTICs at € 169 million overall and € 1.1 per European household. WESSELER et al. (2007) determined MISTICs for GM insect-resistant (IR) and HR maize for different European countries. For IR maize, they found values ranging from € 157.34/hectare for Greece to € 268.73/hectare for Spain. For HR maize, they found values ranging from € 14.97/hectare for Belgium to € 134.95/hectare for Spain. These studies are based on a similar real op-

7 MISTICs per hectare do not consider an adoption process and assume a rapeseed cultivation every third year.

tions concept as used in this study; however, they differ with respect to their modelling assumptions including the determination of the incremental benefits, the adoption process and the economic evaluation of carbon. It is important to point out that in general MISTICs for single GM crops are quite small but. For a more a more general socio-economic assessment of GM crops the sum of MISTICs for all different possible GM crops needs to be considered.

The economic valuation of environmental impacts using carbon emission-related proxy variables remains challenging. As described earlier, we value carbon using the proxy variables suggested by TOL (2011) at € 65.18/tonne of C. Additionally, we tested the robustness of our model using alternative price assumptions. First, we assumed a price of €5.68 for one tonne of CO_2 equivalent, as this is the average trading price at the German Emissions Trading Authority for the first six-month period of 2014 (DEHST, 2014). Second, we set the price for one tonne of CO_2 at € 77.4 as suggested by PRETTY et al. (2000) – a value that has been used in other MISTICs-related studies (DEMONT et al., 2004; WESSELER et al., 2007). Using these prices results in derivation of MISTICs (with yield increase) per citizen of € 12.05 and € 14.57, respectively.

5 Conclusion

This study evaluated the positive economic and environmental effects of introducing GM HR rapeseeds in the German market. By applying a real options approach and considering flexibility, irreversibility and uncertainty, we quantified the ex ante value and estimated the MISTICs as € 13.8 per German citizen. Further, we estimated an option value $[F(W)]$ of € 249.058 million for the possibility of access to the technology for German society. These values provide important information for decision makers. However, it remains their task to weigh these benefits against the potential irreversible hazards from immediate deregulation of GM HR rapeseed cultivation. In addition, regulatory decisions are influenced by complex set of political factors that go well beyond the consideration of social benefits and costs. Thus, the European regulations on GM crops reflects different conflicting political interests and powers, which addresses GM crops in general and not specifically GM HR rapeseeds. Still, the combination of low MISTICs value of GM HR rapeseeds and a generally negative consumer's attitude towards GMOs (European Commission, 2010) indicates a low political probability for the approval of GM HR rapeseeds in the near future. Regarding MISTICs, we only calculated a threshold value. The remaining question is whether the actual incremental irreversible costs will exceed the MISTICs. The next step in the process of finding the socially optimal solution requires determination of whether consumers are willing to bear the MISTICs as a price for not introducing GM HR rapeseeds.

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